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## Landslide-inventory of the Cinque Terre National Park (Italy) and quantitative interaction with the trail network

Emanuele Raso <sup>a</sup>, Andrea Cevasco <sup>b</sup>, Diego Di Martire <sup>a</sup>, Giacomo Pepe <sup>b</sup>, Patrizio Scarpellini <sup>c</sup>, Domenico Calcaterra <sup>a</sup> and Marco Firpo <sup>b</sup>

<sup>a</sup>Faculty of Mathematics Physics and Natural Sciences, DISTAR, University of Naples Federico II, Napoli, Italy; <sup>b</sup>Faculty of Mathematical Physical and Natural Sciences, DISTAV, University of Genoa, Genova, Italy; <sup>c</sup>Ente Parco Nazionale delle Cinque Terre, Riomaggiore, Italy

### ABSTRACT

The Cinque Terre National Park (38 km<sup>2</sup>) has recently recorded a remarkable increase in tourists involved in outdoor activities such as hiking. However, due to the actual slope degradation issues that affect this outstanding terraced landscape, hiking trails are increasingly threatened by the impact of landslides. This produces severe landslide-related risk scenarios for hikers. In this study, a landslide inventory map (at 1:45000 scale) has been prepared through the revision/update of previous database and the analysis of air-photos and satellite images coupled with field surveys. Furthermore, a quantitative evaluation of the interaction between landslides and hiking trails has been performed by the definition of a Footpath Landslide Index. More than 400 landslides were identified highlighting that these phenomena represent the main source of hazard. The findings of this study reveal that side-hill trails are the most hazardous since hikers can be potentially affected by flow-like or fast-moving landslides.

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## 1. Introduction

Landslides are considered worldwide as one of the most important and frequent natural hazards as their occurrence can directly impact humans, infrastructures, economic activities and the environment (Kjekstad & Highland, 2009; Petley, 2012). In Italy, for example, despite less severe human and economic losses with respect to earthquakes, slope instabilities represent the most frequent geomorphological hazard and their temporal probability has been increased in the third millennium (Gariano & Guzzetti, 2016; Guzzetti, Carrara, Cardinali, & Reichenbach, 1999; Salvati, Bianchi, Rossi, & Guzzetti, 2010). Notoriously, the landslide occurrence can be controlled by several factors, which can be subdivided into predisposing and triggering factors. The former include intrinsic factors that make an area prone to slope instability such as slope (Dai, Lee, & Ngai, 2002; Guzzetti, Reichenbach, Ardizzone, Cardinali, & Galli, 2006), lithology (Duman et al., 2005; Chacón, Irigaray, Fernandez, & El Hamdouni, 2006), aspect (Calvello, Cascini, & Mastroianni, 2013; Guzzetti, 2005), land use (Cevasco, Pepe, & Brandolini, 2014; Glade, 2003; Matthews, Brunsden, Frenzel, Glaser, & Weiß, 1997; Van Beek & Van Asch, 2004), vegetation cover (Cammeraat, van Beek, & Kooijman, 2005; Gonzalez-Ollauri & Mickovski, 2017), distance

from rivers and roads (Bordoni et al., 2018; Donnini et al., 2017). The latter are represented by factors that actually trigger the landslide such as intense or prolonged rainfall, earthquakes, rapid snow melting and human activities (Anderson & Holcombe, 2013; Corominas et al., 2014; Crosta, Agliardi, Frattini, & Soso, 2012). As known, landslides can involve toppling or falling, translational/rotational sliding, flowing, lateral spreading, but in most cases, they exhibit a combination of different types of movement (Crozier, 1986; Hungr, Leroueil, & Picarelli, 2014; Hutchinson, 1988; Varnes, 1978).

Landslide Inventory Maps (LIM) are basic elements of both landslide zoning and land-use planning (Fell et al., 2008) and they represent powerful and easily understandable tools for researchers and stakeholders involved in landslide risk management (Galli, Ardizzone, Cardinali, Guzzetti, & Reichenbach, 2008; Guzzetti et al., 2012; Lazzari & Gioia, 2015; Raspini et al., 2016). Moreover, landslide inventories are essential to understand the evolution of landscapes (Blahut, Van Westen, & Sterlacchini, 2010) and for climate impacts research (Wood, Harrison, & Reinhardt, 2015).

The first step of every landslide hazard and risk analysis requires the production of a reliable LIM (Corominas et al., 2014; Godt et al., 2008; Samia et al., 2017). This is crucial for areas where people,

properties, cultural and environmental heritages are exposed to landslide phenomena that pose a serious threat in terms of potential consequences.

Among the 54 UNESCO World Heritage Sites of Italy, the Cinque Terre National Park (Liguria region, northwestern Italy) is one of the most popular and visited tourist destinations. Every year, on average, more than three million tourists visit this outstanding terraced coastal landscape in order to practice hiking. The hiking trails running along the steep terraced slopes allow tourists to appreciate the outstanding equilibrium between the human activity and the natural landscape. In this area, human has modified large portions of natural slopes to develop agricultural practices. Extensive dry-stone terraces were built by reworking soil slope covers along with some ancient landslide bodies (Brandolini, 2017; Terranova et al., 2002). However, land use changes (e.g. farmland abandonment) that took place in the last century have led to terraced slope degradation with negative consequences on slopes stability, especially when intense rainfall occurs (Brandolini et al., 2018a; 2018b; Cevasco, Brandolini, Scopesi, & Rellini, 2013a; Del Monte et al., 2015; Persichillo et al., 2016). Simultaneously, the exponential growth of tourism recorded during the last decades has produced a remarkable increase in landslide-related risk scenarios.

The main aim of this work is the recognition and mapping of landslide type and size in the Cinque Terre National Park and the assessment of the interaction of landslides with the pedestrian trail network, being one of the most popular tourist attractions. To this purpose, using an open source Geographic Information System (GIS), a LIM was prepared through archive information, air and satellite photo-analyses and field activities (Ardizzone et al., 2012; Conforti, Muto, Rago, & Critelli, 2014). Subsequently, the spatial distribution of landslide phenomena and their features (e.g. size and type of movements) have been compared with the Cinque Terre Park's trail inventory, which was obtained from both an accurate bibliographic research and detailed field surveys.

## 2 . Study area

The Cinque Terre area (literally Five Lands) is a 38 km<sup>2</sup> wide coastal sector of the eastern Liguria region (northwestern Italy) which embraces five small towns (less than 4000 total inhabitants) connected by several coastal pathways that represent a worldwide-known tourist attraction. Since 1997, this area has been included in the 'World Heritage List' of UNESCO for its high scenic and cultural value, being one of the worldwide referenced 'cultural landscape', while in 1999 it has been declared as National Park for its environmental and naturalistic relevance. The most

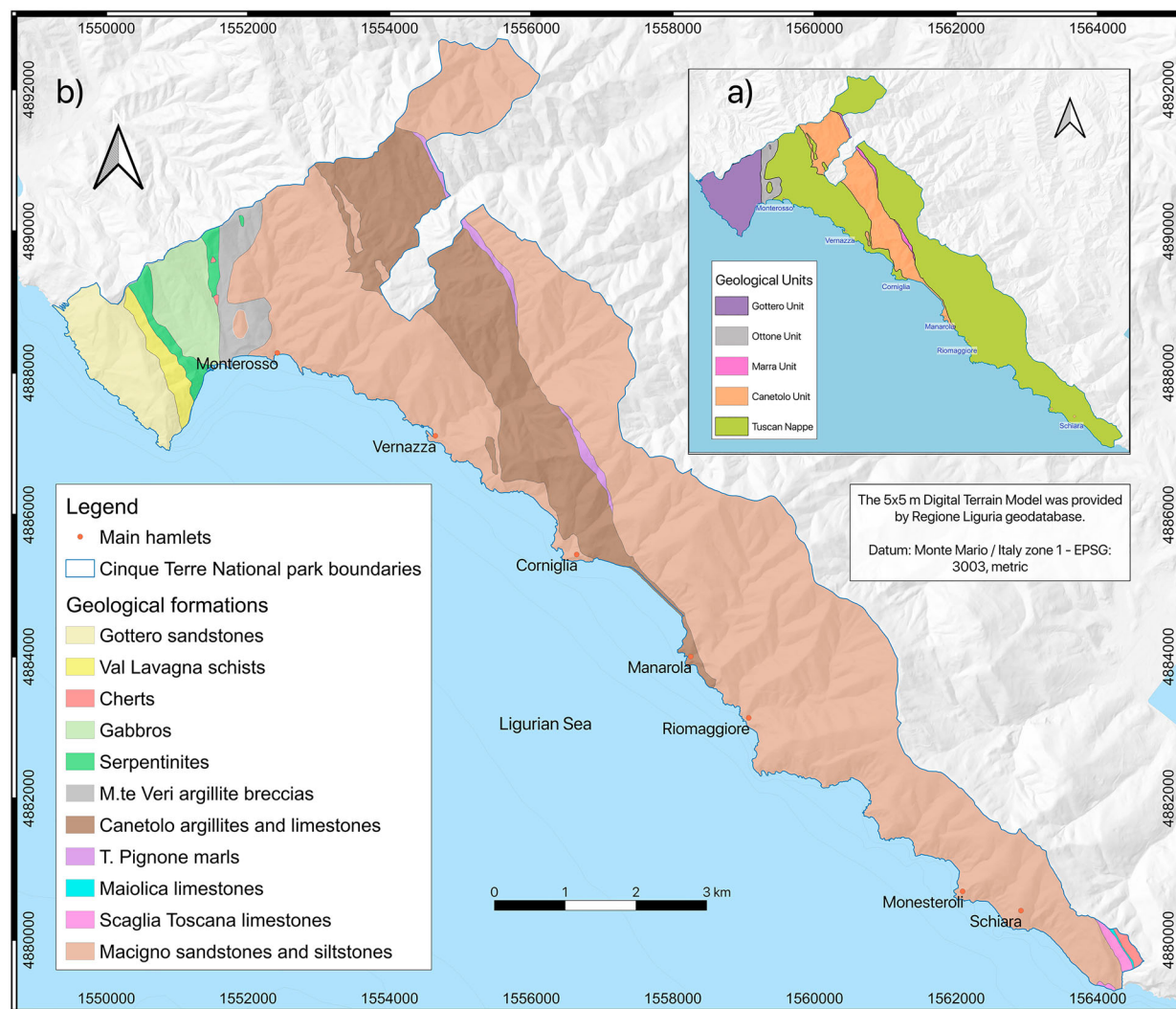
relevant feature of this coastal sector is the terraced landscape, which is characterized by agricultural terraces retained by thousands of kilometers of dry-stone walls, mainly built for vineyards and olive groves (Brandolini, 2017; Terranova, 1984). As reported by Terranova et al. (2002), it can be assumed that in the nineteenth century terraced slopes covered up to 60% of the whole Cinque Terre territory.

Terraces have been recently recognized from UNESCO as world cultural heritage due to their environmental and historical value (Aplin, 2007; Phillips, 1998). Moreover, it is widely documented (Canuti, Casagli, Ermini, Fanti, & Farina, 2004; Lasanta, Vicente-Serrano, & Cuadrat-Prats, 2005; Lesschen, Cammeraat, & Nieman, 2008; Moreno-de-las-Heras et al., 2019 and references therein) that farming terraces, if properly maintained, improve slope stability and prevent runoff and erosion processes.

In the Cinque Terre area, the remarkable farming abandonment occurred since 1950s produced severe terraced slope degradation issues (Agnoletti, Errico, Santoro, Dani, & Preti, 2019; Brandolini et al., 2018b; Conti & Fagarazzi, 2004). This pose serious threats to human settlements, inhabitants and trail users as dramatically observed after the intense rainstorm that hit this sector of eastern Liguria on 25 October 2011 (Cevasco et al., 2013a; 2015; Galanti, Barsanti, Cevasco, D'Amato Avanzi, & Giannecchini, 2018).

### 2.1 . Geological, geomorphological and climatic setting

Geologically, the territory of the Cinque Terre National Park belongs to an NW–SE oriented segment of the Northern Apennine, an orogenic chain formed during Tertiary (Abbate, Bortolotti, Passerini, & Sagri, 1970). This sector of belt is made up of a nappe sequence that includes five overlapping tectonic units (top to bottom): Gottero Unit, Ottone Unit, Marra Unit, Canetolo Unit and Tuscan Nappe (Figure 1(a)). The Gottero Unit crops out in the westernmost sector of the study area, along the NE–SW trending headland of Punta Mesco, and mainly consists of ophiolite rocks (classically interpreted as the remnants of the Jurassic oceanic crust), followed by a turbidite sequence (Late Cretaceous). The Ottone, Canetolo and Marra units are localized in the western side of the Monterosso village and in the central sector of the national park (Figure 1(b)). The first one is prevalently composed by pelitic rocks (Monte Veri Complex Fm.). The other ones occupy a narrow NW–SE oriented stretch of land encompassing the coastal villages of Manarola and Corniglia and it includes claystones with limestones and silty sandstones turbiditic rocks (Figure 1(b)). The Tuscan Nappe occupies most of the Cinque Terre National Park as it outcrops on the eastern, central and



**Figure 1** . Geology of the Cinque Terre National Park (modified after Raso et al., 2019): (a) tectonic sketch map, (b) geological map.

western sectors. This unit is almost entirely represented by thick sandstone-claystone turbidites (Macigno Fm.), largely cropping out along the coast, and secondly by limestones, only cropping out in the easternmost part of the national park (Figure 1(b)). The main structural setting of the study area is predominated by a wide overturned SW-verging antiform fold (Giammarino & Giglia, 1990) and by multiple sets of Plio-Quaternary tectonic discontinuities that in turn strongly influence the local morphology such as coastline, hydrographic network, main and secondary watersheds (Cevasco, 2007). The morphological features of the Cinque Terre area show a sequence of small coastal basins delimited from the inner Vara Valley by the main water divide approximately running parallel to the coast, which consists of sub-vertical rocky cliffs shaped by the wave action at the basal portion (Cevasco, 2007; Raso et al., 2017). Such basins are dominated by steep and very steep slopes (more than 50% of the slope gradient is greater than 30°) covered by thin and human-reworked eluvial-colluvial deposits (Cevasco, Pepe, & Brandolini, 2013b),

short streams or channels and narrow V-shaped valleys whose bottoms are often occupied by the main villages. This morphological framework is locally interrupted by lower steep slopes hosting some important dormant or relict landslide bodies.

The climate of this sector of Liguria is of Mediterranean type and characterized by warm dry summers and temperate winters (mean annual temperature of 14.5–15.5°C) whereas the average annual precipitation is about 1000 mm, with the rainiest period generally comprised between October and November, when very intense rainstorms often can occur (Cevasco, Pepe, D'Amato Avanzi, & Giannechini, 2015).

## 2.2. Trail network

The footpaths of the Cinque Terre have been the only connection between the coastal villages and the hinterland for centuries. Today, the hiking trail network develops along more than 100 km and it allows millions of yearly visitors to admire and enjoy the whole territory of Cinque Terre through different types of paths.



In the past, various tracts of the Cinque Terre hiking trails have been often affected by several landslides triggered by different causal factors (e.g. intense rainfall, temperature variation, wild animals), sometimes also endangering hikers (Raso, Faccini, Brandolini, & Firpo, 2016). For instance, from 1980 to 2012, about twenty rockfall events have been documented along the trail known as *Via dell'Amore*, which is one of the most famous and visited coastal paved path linking the hamlet of Manarola with the one of Riomaggiore (Raso et al., 2016). In 2011, near the villages of Vernazza and Monterosso, some rainfall-induced flow-like landslides impacted the hiking trails causing damage along with local interruptions (Brandolini & Cevasco, 2015; Cevasco et al., 2013a). The landslides triggered along the escarpments and/or the dry-stone walls that insist on hiking routes represent therefore a serious issue. As a consequence, some civil protection measures have been undertaken during the last years by the Cinque Terre National Park authority. According to the Italian civil protection system, four levels of warning for the hydro-meteorological risk are established (from the least to the most dangerous): Green, Yellow, Orange and Red alert. Such alert levels are issued by Liguria region administration through the technical and scientific support of the regional Hydro-Meteorological Monitoring Centre (CFMI-PC). For each warning level different hazard- and consequence-related scenarios are expected. The issuing of the Red alert level indicates the high probability of occurrence of severe rainstorms that may produce a significant increase of the hydro-metric levels along with large floods and numerous and extensive landslide phenomena. In case of the Orange alert level, an increase of river levels, local flooding together with widespread shallow and flow-like landslides are expected due to rainfall. Eventually, during the Yellow and Green alert levels, rainfall-related hazard scenarios can be considered occasional and characterized by low to very low probability of occurrence, respectively. In this framework, when an orange or red weather alert is in force, the Cinque Terre National authority arranges for the trail network to be closed to visitors. However, also under less severe weather conditions (i.e. Green and Yellow alert levels), the Cinque Terre National Park authority reminds that paths must be always walked only with appropriate shoes and by people having a good hiking experience. This measure further contributes to avoid injuries and therefore to decrease the numbers of people potentially exposed to geo-hydrological risk.

### 3 . Methods

#### 3.1 . Landslide inventory

In this study, a recognition and partial reworking/revision/update of the pre-existing national landslide

inventories such as IFFI (Inventario Fenomeni Franosi Italiani – Landslides Inventory of in Italy – <http://www.isprambiente.gov.it/it/progetti/suolo-e-territorio-1/iffi-inventario-dei-fenomeni-franosi-in-italia>) and AVI (Areas affected by landslides or floods in Italy – <http://avi.gndci.cnr.it/>) and of previous researches (e.g. Cevasco, 2007; Raso et al., 2019) was performed through the visual interpretation of satellite images and aerial photos integrated by field validations and observations. Simultaneously, the existing inventories of the hiking trails (provided by National Park Service as vector layers) were revised and completed by field activity using a GPS device.

Geomorphological field surveys were carried out on topographical maps at 1:5000 scale between September and November 2018 whereas remote sensing activities were carried out on Landsat<sup>TM</sup> and Google<sup>TM</sup> satellite images, digital georeferenced orthophotos taken from both Friuli-Venezia-Giulia Regional Administration (ground resolution of 3–50 cm, depending on altitude and dating to November 2011) and Regione Liguria Administration (1:5000 scale and dating to 2016) and through the use of data obtained from a GNSS monitoring which started in 2015: a series of permanent monitoring stations equipped with low cost single-frequency GNSS receivers was positioned along some of the main landslides in the Cinque Terre National Park with the aim of detecting displacements of a few millimeters (Raso et al., 2017). Data collected from field and remote sensing activities were then georeferenced and digitized as polygons within a GIS environment. Based on the scale adopted in mapping activity, we considered landslides larger than 25 m<sup>2</sup>. A database containing attributes of the landslide size (i.e. area), intensity (according to Lateltin, Haemmig, Raetz, & Bonnard, 2005), type (according to Cruden & Varnes, 1996 and Hungr et al., 2014) was created for each mapped slope instability. The obtained LIM was represented at 1: 45000 scale where the mapped landslides were overlaid on a shaded relief base derived from a digital elevation model (DEM) created using 1:5000 scaled vector topographic maps provided by the Regione Liguria Administration. The cartographic representation of the [main map](#) was completed with hiking trail paths, 20-m interval contour lines, main reliefs and toponyms.

#### 3.2. Interaction between landslides and hiking trails

As reported in technical literature (Corominas et al., 2014; Hungr, 1997), the destructive power of a landslide is better expressed by its intensity rather than its magnitude, which describes landslides only in terms of size (i.e. area or volume).

The assessment of landslide intensity is a difficult problem since intensity is not an inherent feature of

the landslide and it can also depend on the peculiarities of the propagation path. Landslide intensity can be described considering a set of quantitative or qualitative spatially distributed parameters like velocity, volume, differential displacement or kinetic energy (Corominas et al., 2014; Hungr, Corominas, & Eberhardt, 2005).

In this research, in order to understand the capability of a given landslide phenomenon to cause damage to trail users, an intensity level (i.e. high, medium and low) was assigned at each landslide. We adopted the approach proposed by Lateltin et al. (2005) according to which a distinction has been made between high-intensity landslides, characterized by high values of kinetic energy and mean annual velocity of 10 cm/day (or >1 m in case of a single event), and low- and medium-intensity landslides, characterized by mean annual velocity displacement lower than 20 cm/year: going into further detail, a low-intensity movement has an annual mean velocity of less than 2 cm/year. A medium intensity corresponds to a velocity ranging from 1 to approximately 10 cm/year. The high-intensity class is usually assigned to shear zones or zones with clear differential movements and it may also be assigned if reactivated phenomena have been observed or if horizontal displacements greater than 1 m per event may occur. Finally, the high-intensity class can also be assigned to very rapid, shallow slides (velocity >0.1 m/day). Subsequently, with the aim of assessing the proneness of any single trail to be hit and damaged by landslides, the Footpath Landslide Index (FLI) was created (Equation (1)):

$$FLI = \frac{[\sum (Lh) + \sum \ln(Ll + 1)] \cdot 100}{Tl}, \quad (1)$$

where  $Lh$  is the Length of hiking trail affected by high-intensity landslides (m);  $Ll$  is the Length of hiking trail affected by low to medium-intensity landslides (m);  $Tl$  is the Hiking trail total length (m).

The FLI takes into account the total length of the trail and the length of the trail stretches that are affected by landslides characterized by different intensity levels. The distinction in two landslide intensity classes (low-medium and high) is mainly due to the fact that high-intensity landslides result to be the main threat for elements exposed to risk along hiking trails (in this case, hikers and tourists). It may be

expected that the larger the FLI value, the higher the potential for damage for trail users due to the impact of a landslide event.

## 4. Results and discussions

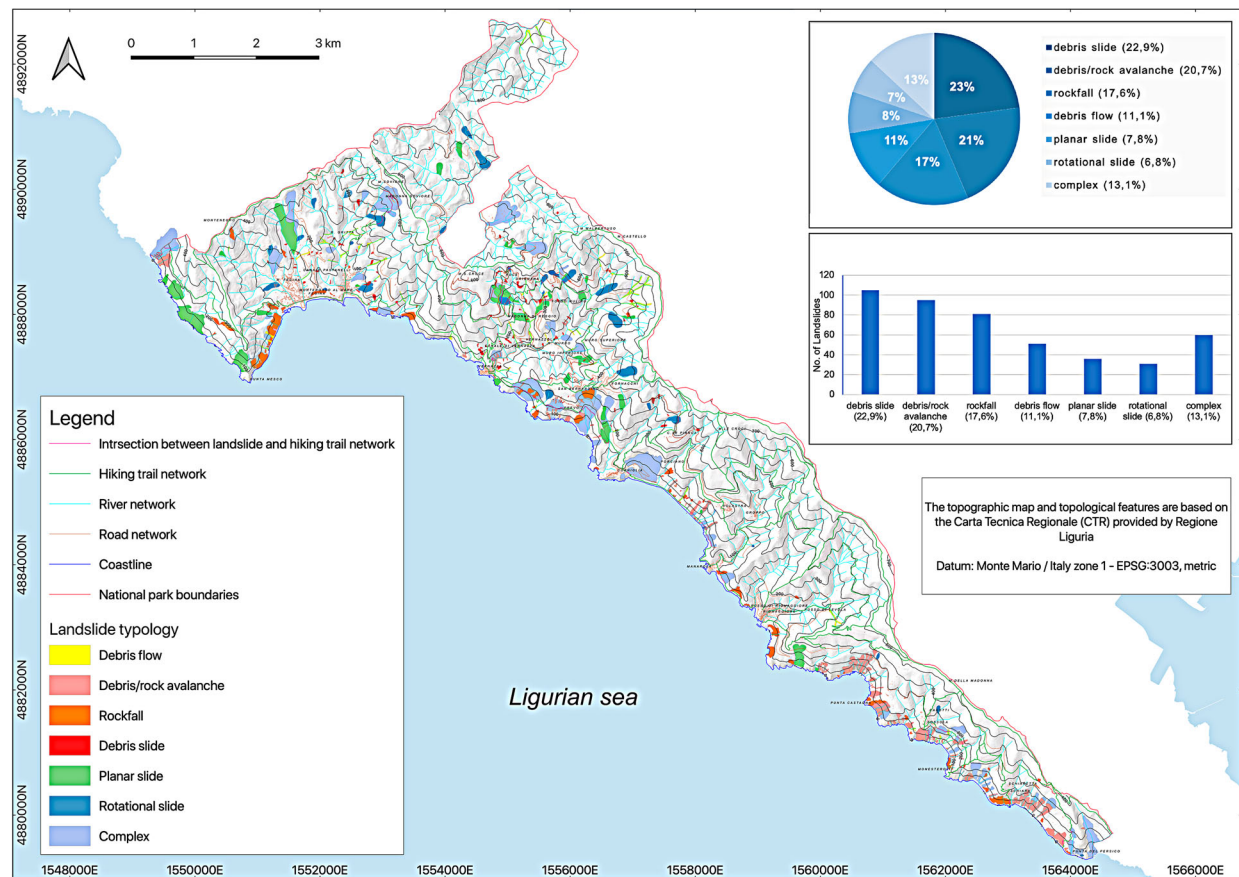
### 4.1. Landslide inventory

The produced LIM highlights how the landslides represent the main geomorphic processes within the Cinque Terre National Park territory and consequently as such phenomena play a leading role in the actual morpho-evolution of the landscape. A total number of 459 landslides (Table 1) were identified and mapped (Figure 2). It is relevant to note that an important number (about 170) of inventoried landslides, particularly of shallow-type, are related to the extreme rainfall event of 25 October 2011, when, in a few hours, approximately 450 mm of rainfall hit the western sector of Cinque Terre National Park belonging to the Monterosso al Mare and Vernazza municipalities (Brandolini & Cevasco, 2015; Cevasco, Pepe, & Brandolini, 2012; Galve, Cevasco, Brandolini, & Soldati, 2015, 2016). Moreover, some mass movements (about 5) were recently triggered on 30 October 2018, when cumulative daily rainfall magnitudes up to 128 mm in 3 h were measured at the Monterosso rain gauge (ARPAL-CFMI-PC, 2018).

The mapped landslides cover a total area of 4.19 km<sup>2</sup>, corresponding to 10.9% of the total surveyed area and to a landslide density of 11.9 landslide/km<sup>2</sup>. The size of the inventoried landslides ranges from a minimum value of 99 m<sup>2</sup> to a maximum one of 179,390 m<sup>2</sup> whereas the average area is 9140 m<sup>2</sup>. Referring to the classification proposed by Cruden and Varnes (1996) and Hungr et al. (2014), inventoried landslides were grouped into seven main landslide types and a percentage distribution analysis was then performed (Figure 2). A high number of mass movements can be classified as debris slides (105–22.9%) and debris/rock avalanches (95–20.7%) which are typical phenomena affecting mountainous and hilly terraced areas, particularly in case of prolonged or intense rainfall events (Camera, Apuani, & Masetti, 2014; Cevasco et al., 2013a; Crosta, Dal Negro, & Frattini, 2003; Schilirò, Cevasco, Esposito, & Scarascia Mugnozza,

**Table 1** . Summary of the main morphometric characteristics of the different inventoried landslide types.

Landslide type	Number of landslides	Minimum area (m <sup>2</sup> )	Maximum area (m <sup>2</sup> )	Average area (m <sup>2</sup> )
Debris slide (22.9%)	105	103	4646	1046
Debris/rock avalanche (20.7%)	95	116	37,348	5560
Rockfall (17.6%)	81	99	29,275	4921
Debris flow (11.1%)	51	370	22,708	3780
Planar slide (7.8%)	36	1814	121,592	20,252
Rotational slide (6.8%)	31	1340	39,341	13,588
Complex (13.1%)	60	2006	179,390	30,264



**Figure 2.** Landslide inventory of the Cinque Terre National Park and diagrams showing the percentage of catalogued landslides for each typology.

2017, 2018) and where terraces are more vulnerable due to farmer abandonment (Brandolini et al., 2018a; Cevasco, Pepe, et al., 2015, 2017; Pepe et al., 2019). In the study area, these mass movement types are prevalently rainfall-induced, shallow and mainly affect the thin veneers of human-reworked eluvial-colluvial slope deposits retained by dry-stone walls (Figure 3(a,b)). Furthermore, these two instability mechanisms are strictly connected to each other in terms of evolution. In fact, during heavy rainfall the debris slides can rapidly evolve into flow-like landslides, such as debris/rock avalanches, that progressively entrain slope materials down the slope, increasing in volume and kinetic energy.

Debris flows are also widely distributed (51–11.1%), especially along the western sector of Cinque Terre, and are promoted by the steepness of first and second order channels (Figure 3(c)). They usually occur simultaneously with flash floods and are characterized by rapid and very rapid surging flows of saturated debris entrained from the flow path and of landsliding materials entered in the channels from the slopes (Cevasco et al., 2013a, 2014).

Rockfalls (81–17.6%) are common along the coastline, typically where sandstones and siltstones, pertaining to the Macigno Fm., widely crop out along cliffs even 50 m high. These types of landslides are frequently connected to the interplay between the

rock mass geo-structural features and the sea action. Due to multiple sets of discontinuities (e.g. joints and cleavages) affecting the rock masses, single or groups of rock blocks can be detached by sliding and/or toppling mechanisms that rapidly evolve into falls (Cevasco, 2007; Raso et al., 2016). These events are frequently triggered by the sea undercutting acting along cliffs and the falling materials are deposited at their toes, often producing well developed talus deposits.

Other landslide types are less numerous and include rotational (31–6.8%) and planar slides (36–7.8%) (Figure 3(d)).

Finally, many landslides (60–13.1%) with complex evolution can be observed along the coastline between the Vernazza and Manarola municipalities (Figure 2). These phenomena (e.g. Guvano, Rodalabia, and Macereto landslides) are historically well-known and extensively described in literature (e.g. Cevasco, 2007; De Stefanis, Marini, Terranova, & De Luigi, 1978; Federici, Baldacci, Petresi, & Serani, 2001; Raggi, Raggi, & Pintus, 2010; Raso et al., 2017; Terranova, 1984, 1989) and usually consist of large relict landslide bodies closely related to stratigraphic/tectonic contacts between rock sequences characterized by different mechanical behavior (Figure 3(e)). Some of these landslides are characterized by localized residual movements and occasional





**Figure 3.** Five examples of different landslide typologies surveyed in the study area: (a) debris slide involving terraced slopes above the hamlet of Vernazza; (b) debris avalanche along the coastline between Corniglia and Manarola; (c) debris flow located in Vernazza, along the Vignaresca stream; (d) planar slide involving Macigno sandstone between Vernazza and Corniglia; (e) Guvano complex landslide.

reactivations with kinematics from extremely slow to very slow (Cevasco, 2007; Raso et al., 2017).

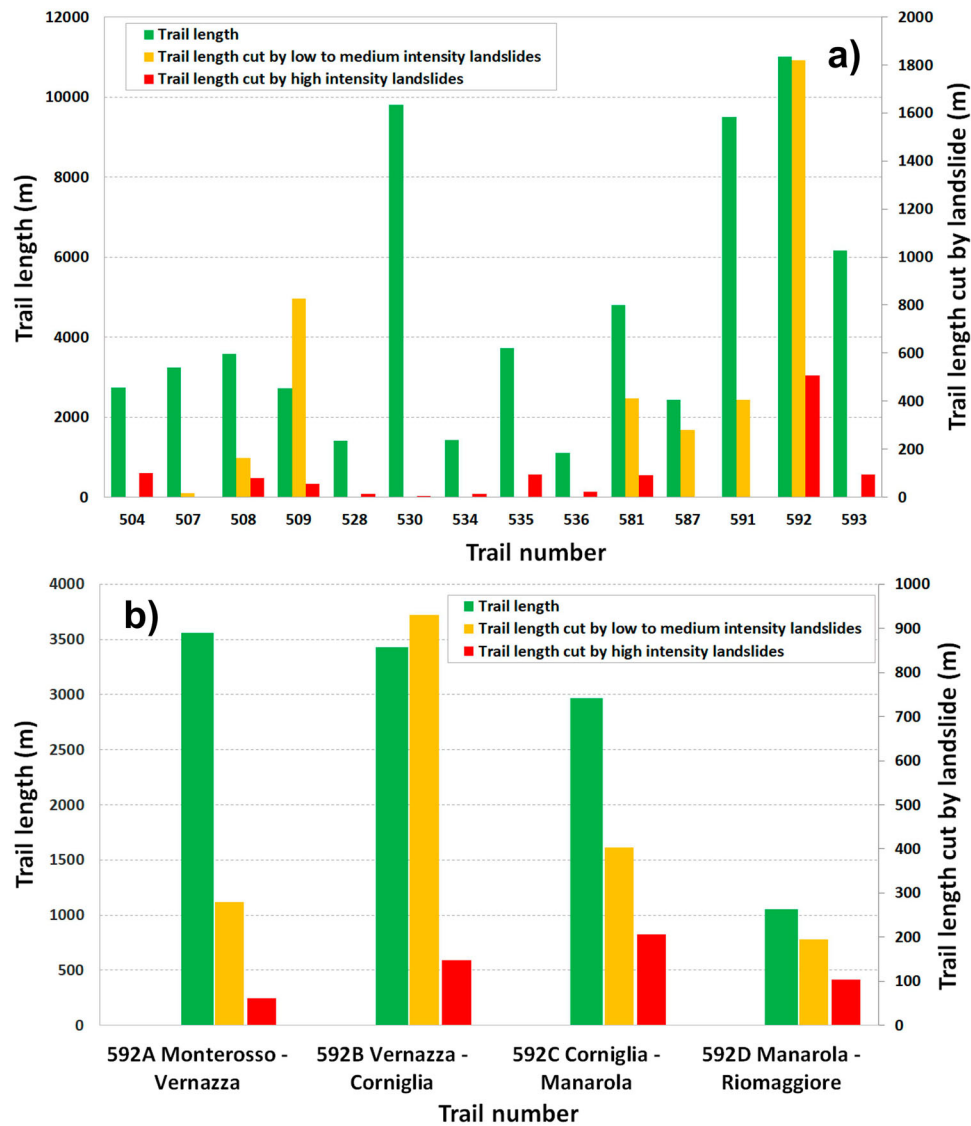
#### 4.2 . Interaction between landslides and hiking trails

On a total length of 104 km of the park's trail system, about 5 km were found to be cut by landslides (Figure 4 (a)). In detail, 3.9 km of the hiking trails resulted potentially intersected by low to medium-intensity landslides while 1.1 km by high-intensity landslides. Among the 14 inventoried hiking trails, only 4 paths (i.e. trails 507, 528, 530 and 534) resulted cut by landslides for very small lengths (ranging approximately between 4 and 16 m). It is worth highlighting the hiking trail number 592 (also known as *Verde-Azzurro* trail), which shows the highest number of visitors per year and that is also characterized by the highest length of path potentially subjected to the impact of landslides (Figure 4(a)). A further partition has been carried out on the 592 trail by distinguishing four main stretches (Figure 4(b)) which connect the five coastal villages of the national park (i.e. Monterosso, Vernazza,

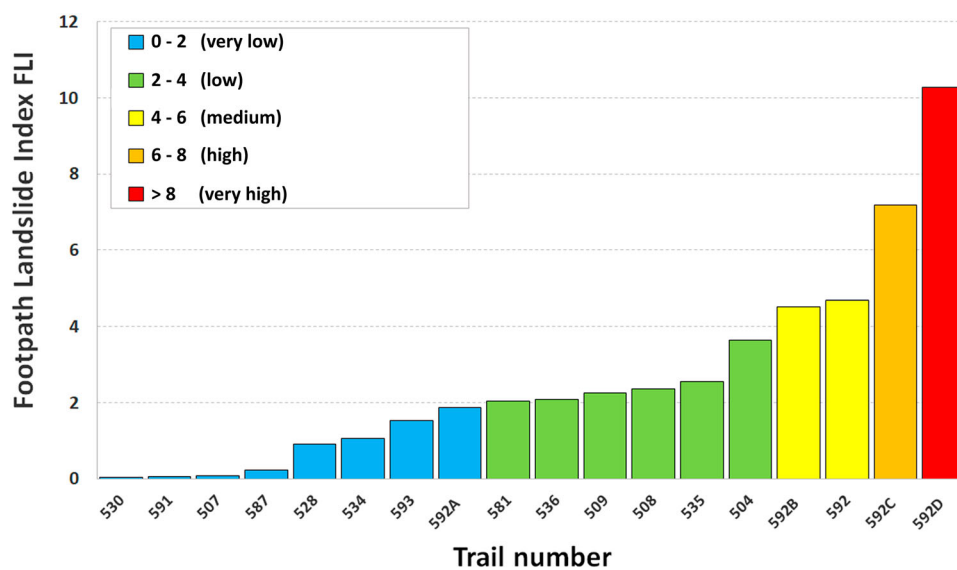
Corniglia, Manarola and Riomaggiore). It is relevant to note that every considered stretch is potentially intersected by landslides (Figure 4(b)).

However, a better characterization of the potential for damage due to landslide impact for exposed elements, and more specifically for hikers walking along the footpaths, can be obtained through the computed Footpath Landslide Index. As can be observed by Figure 5, the FLI values vary between 0 and 10.3. The highest values of FLI are associated to the trails 592D and 592C (10.3 and 7.2, respectively) and highlight that the landslides intersecting these two stretches can cause significant damage to hikers. These results are in agreement with previous researches (Raso et al., 2016) that documented nine main rockfall events which affected the 592D trail stretch from 1990 to 2012. These landslide events lead to the closure of the path and in two cases they also involved the path users. Further interesting observations come from the mapping of the FLI values for the whole Cinque Terre National Park's hiking trail system (Figure 6). It is interesting to note how hiking trails showing values of FLI higher than 3 (high FLI) are usually

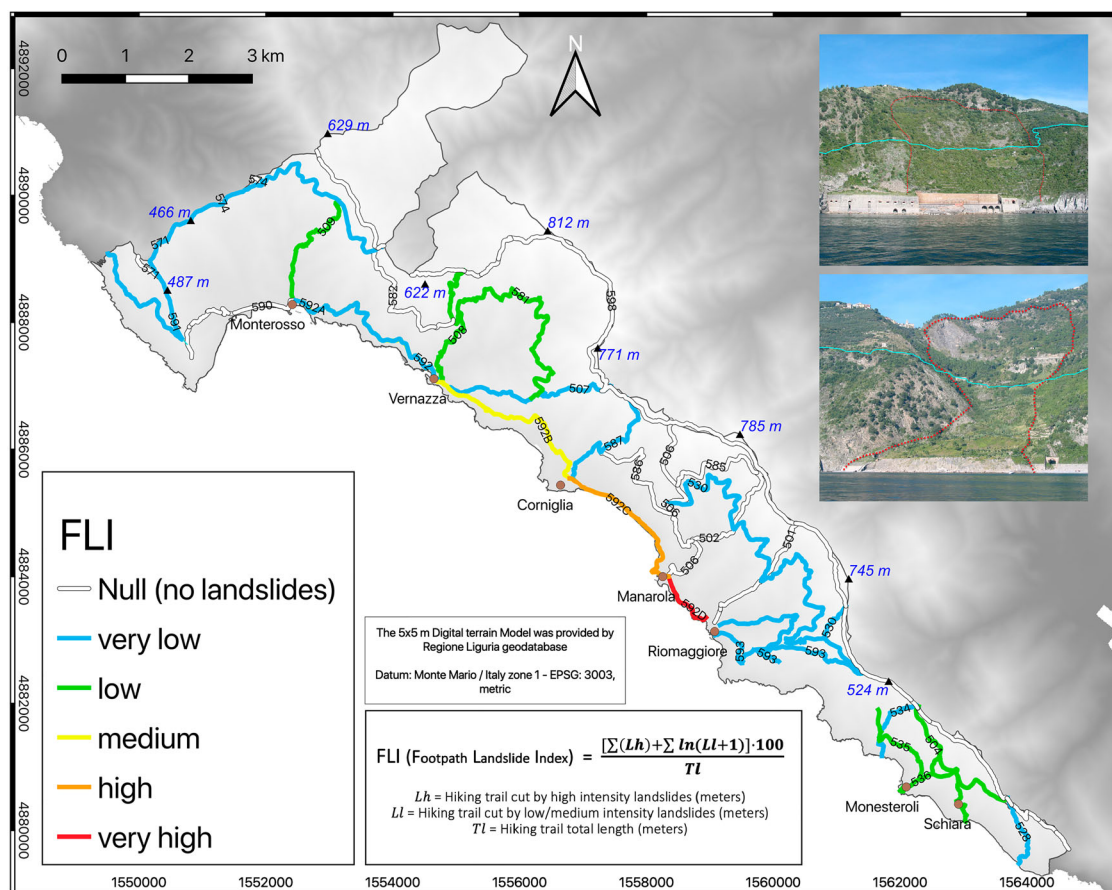




**Figure 4.** (a) Trail lengths and landslide intersections in the Cinque Terre National park and (b) 592 trail sectors length and landslide intersection along the 'Sentiero Verde-Azzurro'.



**Figure 5.** FLI (Footpath Landslide Index) ranked in ascending order per each trail.



**Figure 6.** FLI (Footpath Landslide Index) extended to all the trails included in the Cinque Terre National Park and examples of side-hill trails.

side-hill trails (Leung & Marion, 1996), namely trails aligned perpendicular to slope gradient or approximately parallel to contour lines, which are often included, in part or completely, along the portion of slope comprised between the coast and the main edge of the erosional coastal scarp (Figure 6). Along such trails, hikers can be potentially impacted either by fast moving or flow-like landslides (e.g. rockfalls and debris/rock avalanches), which are slope instability mechanisms very frequent along the coastal strip comprised between 0 and 200 m a.s.l. (Cevasco, 2007; Raso et al., 2016, 2017). Conversely, the upper trails, such as the 530, 591 or 507, show very low values of FLI (less than 2). This is related to the fact that such trails are prevalently fall-aligned paths (i.e. aligned congruent to the slope gradient) that are often aligned with ridges, and therefore are less prone to be affected by landslides (Figure 6).

## 5. Conclusions

The Cinque Terre National Park is visited by millions of tourists every year to practice hiking. However, this area is chronically characterized by high landslide susceptibility due to its geological, geomorphological and land-use setting. Accordingly, the recent exponential growth of trail users has produced a remarkable

increase in landslide-related risk scenarios. In this study, both an inventory of landslide phenomena and of hiking trails has been prepared at 1:45000 scale. The main map was derived from the revision/update of previous inventories, the analysis of air-photos and satellite images and from field surveys. Moreover, the proneness of hiking trails to be impacted by landslides has been estimated by the Footpath Landslide Index. The produced LIM confirms that landslides represent the main source of hazard for the whole Cinque Terre National Park. These phenomena are characterized by a wide variety of types, each one characterized by different magnitudes and intensities. Furthermore, the study reveals that side-hill trails are the most hazardous since hikers can be potentially affected by flow-like or fast-moving landslides.

This study can provide a relevant contribute to tourism planning and management in the study area. Our findings may be useful to define the trails which need proper management of hikers to access and to schedule the hazard mitigation measures so as to decrease the landslide-related risk levels. Moreover, the produced landslide inventory provides some basic input data to produce reliable landslide susceptibility, hazard and risk zoning maps of the Cinque Terre National Park.

Eventually, geomorphological data acquired in this work represent an updated contribution to understand

the influence of landslide processes on the landscape evolution of the area. Such data can be conveniently used by local administrations and authorities for an efficient allocation of resources in landslide risk management strategies.

## Software

The topographic base, the landslide inventory map and the related layout were drawn using open source software (QGIS 2.18.2, 3.4.2 and Grass 7).

## Disclosure statement

No potential conflict of interest was reported by the authors.

## ORCID

Emanuele Raso  <http://orcid.org/0000-0003-2820-7233>  
 Andrea Cevasco  <http://orcid.org/0000-0002-0559-4835>  
 Diego Di Martire  <http://orcid.org/0000-0003-0046-9530>  
 Giacomo Pepe  <http://orcid.org/0000-0002-5435-6462>  
 Domenico Calcaterra  <http://orcid.org/0000-0002-3480-3667>

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